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Title: MCNP6 Dose Calculations for the Carousel in the LDRGIF

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MCNP6 Dose Calculations for the Carousel in the LDRGIF

R. W. Brewer and B. A. Temple

Executive Summary

All calculated results are satisfactory. The 66% confidence intervals for all results are less than 5%. A comparison was made between a simple model and a detailed model. The simple model consists of the source, room wall, the carousel Al disks, sample cans, and the samples. The detailed model includes the entire simple model along with the safe, and all of the details of the carousel. There was no difference between the two models for the dose absorbed by the samples. If these calculations are performed in the future, one should use the simple model. The simple model runs faster and the results are easier to understand.

Dose rates to various polymers in the carousel assembly were calculated. The source of radiation is a 6.61 curie ^{137}Cs source. The experiments are planned for Bldg 6631. LK3626 absorbed the largest dose, 791000±554 rads/yr. The lowest absorbed dose is 696000±487 rads/yr. The lowest absorbed dose is for the gold disk #1 and TLDs 1a and 1b, Au disk 658000±3950 rads/yr and TLD 1a 481000±4450 rads/yr. The Au disk with the highest absorbed dose is #3 at 3640000±9460 rads/yr. The TLD with the highest absorbed dose is 6a at 1820000±106 rads/yr.

Introduction

This experiment is designed to study the effects of radiation on a number of polymers. The experiment is to be performed at Bldg 6631, which is also known as the LDRGIF. A sketch of the room in the LDRGIF is shown in Figure 1. The wall has numerous lead bricks stacked to minimize radiation from this experiment from interfering with other experiments in adjacent rooms, in Figure 1, it is colored magenta. There is a steel wall to shield the door for entry into the control room or other rooms, blue in Figure 1. The inner dimensions of the room are 228 inches (width), 279 inches, by 118 inches (height).

The carousel is located in the corner of the room. A photograph of the carousel is shown in Figure 2. The 6.61 Ci ^{137}Cs source is mounted on a steel rod and is represented by the orange cap. The rod supporting the ^{137}Cs source is 42 cm long. The carousel is constructed of Al type 5052. The cans, which contain the polymer samples, can be seen evenly spaced around the carousel. The top Al plate is 1/8 inch thick and the bottom is ¼ inch thick. The eight sample holes are evenly spaced around the Al plates on 20 cm radius circle. The holes are 22.5° from the vertical or horizontal in the Al plate plane. The holes themselves are 45° from each other. The holes are 1.5 inches in diameter, both top and bottom. The gap between the Al plates is 2.53 inches.

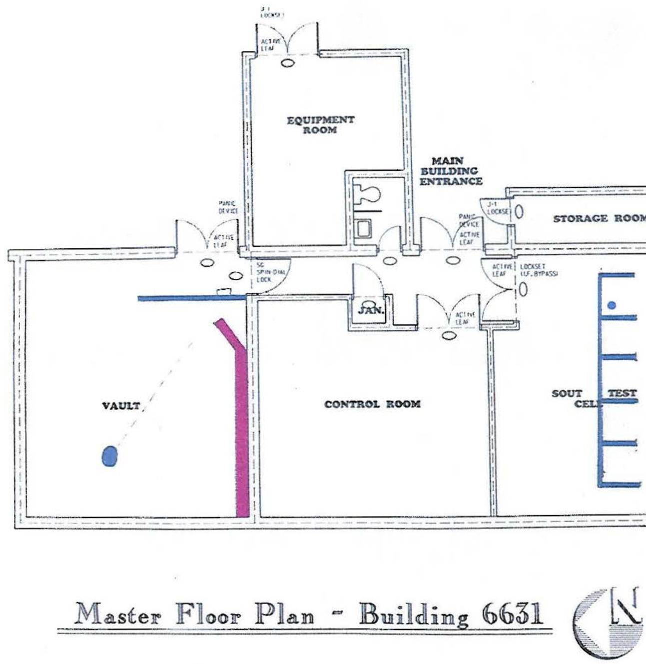

Figure 1: Sketch of Building 6631

Figure 2: Photo of the Carousel

An engineering drawing of the sample cans was available to the analysts. The engineering drawing of the cans is proprietary. The description will not be given in this report. The cans are constructed of Al, both can and cap. As can be observed in Figure 2, the caps rest on the upper surface of the upper carousel Al plate.

Models

Simple Model

The ^{137}Cs source is encapsulated, and as stated previously is 6.61 Ci. The source itself is cylindrical with a height of 7.92 mm (0.792 cm) and a radius of 0.396 cm. The steel rod supporting the source is threaded and screwed into the top Al plate. The rod is 42.67 cm long and has a radius of 0.475 cm. In the photos, the source is shown with an orange cap. It appears that the orange cap is used to simulate the ^{137}Cs source.

Figure 3 shows the MCNP model of the room in the X-Z plane. On the positive end of the X axis is the lead brick shielding. The lead is plotted as the color green. The cinder block walls are magenta. Obviously, the lead bricks were used to shield the control room, in Figure 1, from the gamma radiation. The Z axis is the floor (negative Z) and ceiling (positive Z) of the room. All of the empty space is occupied by a simple air composition and is blue.

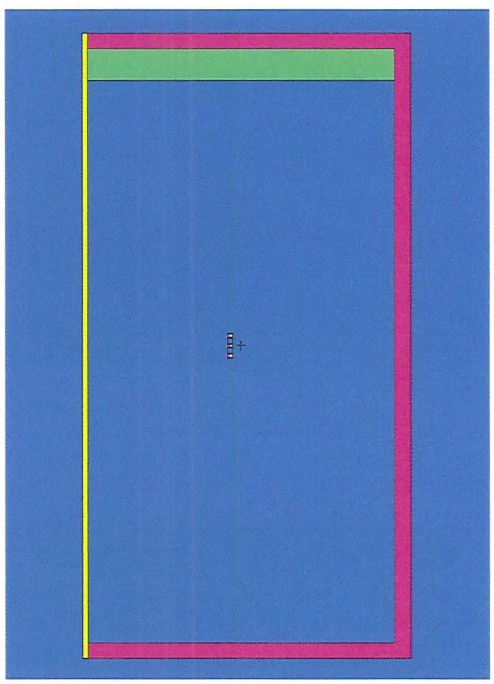

Figure 3: Simple Model, Side View (X-Z)

Figure 4 shows the X-Y plane of the room. The green is the lead shielding. The magenta is the cinder block walls. The yellow is a steel wall that shields the door. It is highlighted in blue for the Figure 1 sketch and not to be confused with the location of the ^{137}Cs source, which is highlighted in blue.

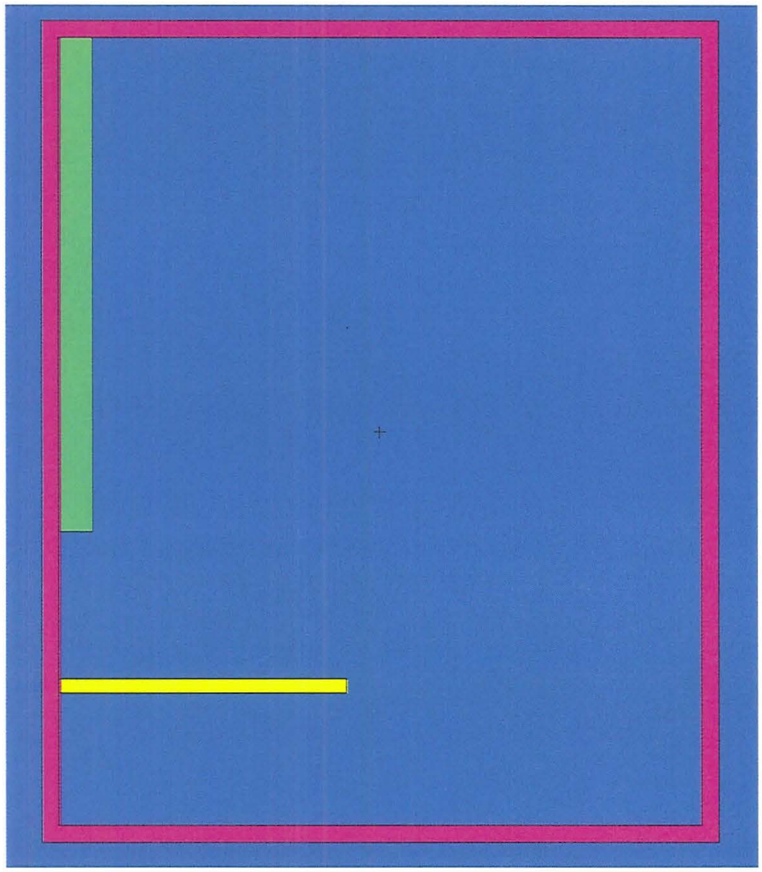

Figure 4: Simple Model, Overhead View (X-Y)

Figure 5 is the room model in the X-Z plane. A simple model of the carousel is shown near the center of the room. Two models were used in the calculations. There is a simple model with the samples, the room, and the upper and lower part of the carousel plates. The more detailed and complex model will be shown later. The roof is modeled as 4 inch thick steel (yellow).

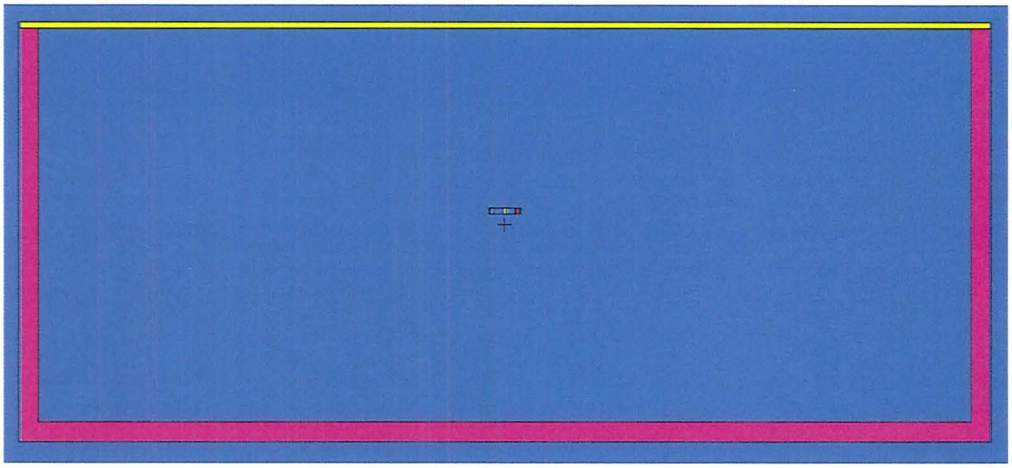

Figure 5: Simple Model, Side View (X-Z)

A side view of the carousel assembly is shown in Figure 6. The top and bottom carousel discs are copper and shown in green. The steel rod that the ^{137}Cs source is mounted on is in yellow. For the simple model the details of the sample cans were modeled with all of the available features. The top and bottom carousel disks are also modeled with as much detail as was given.

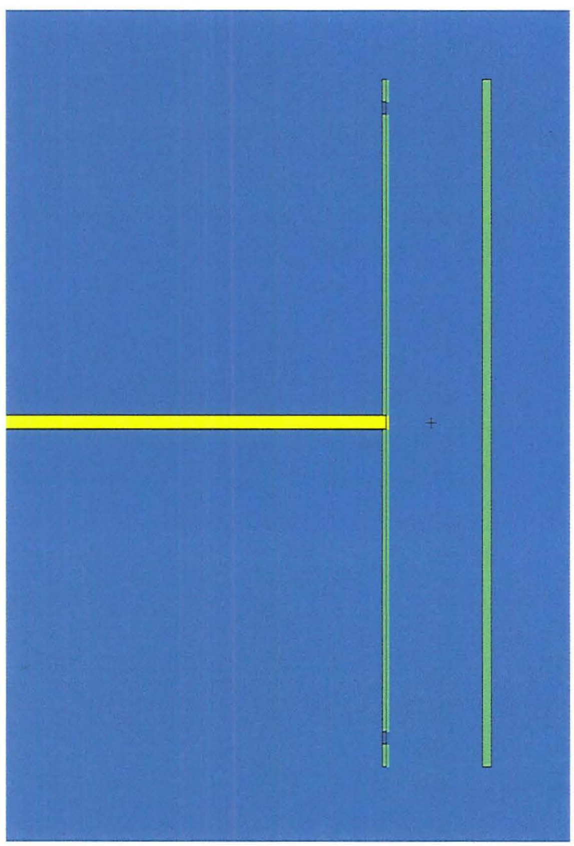

Figure 6: Simple Model, Carousel Side View

A cross-section of the top copper carousel disc is shown in Figure 7. The ^{137}Cs support rod extends out from the center in the positive Z direction. The source support rod is 316 stainless steel. The rod is 42.67 cm long and is threaded into the top disk. Four alignment holes were bored through both the top and bottom disks. The holes are occupied by air (blue).

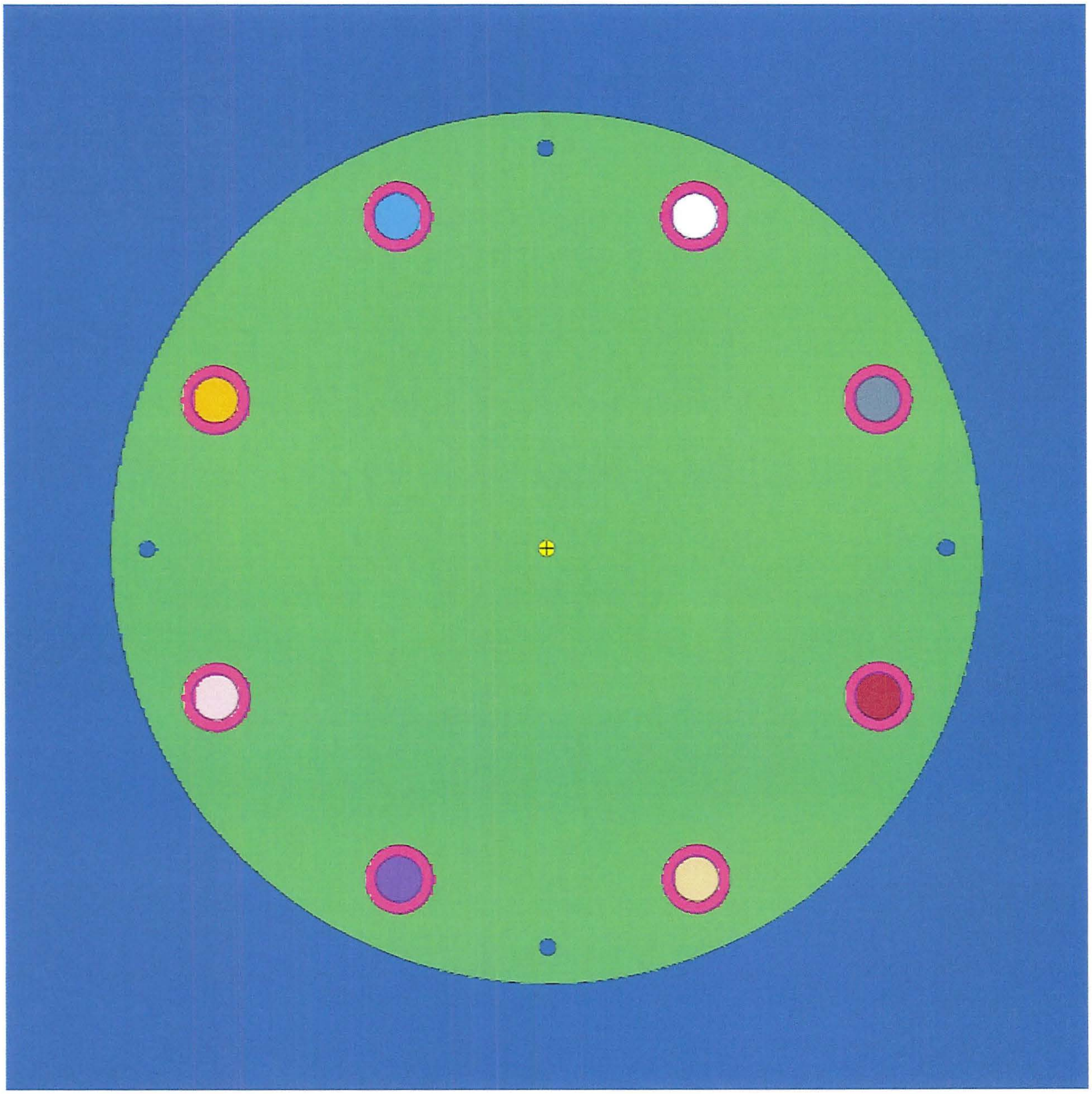

Figure 7: Simple Model of Carousel, Overhead View

Detailed Model

A side view of the detailed model is shown in Figure 8. The number of materials increases by a factor of 2 and colors do not match the simple model. For example, air is blue in the simple model, while air is green in the detailed model. The steel is in royal blue, and in this figure, it is the safe that houses the carousel and the ^{137}Cs source. The safe door is shut. The detailed model can calculate doses with the safe door open or closed. The small apparatus to the left of the safe are radiation detectors (NaI and BGO). The carousel is in, approximately, the middle of the safe and appears to float in air. The supports are not to any of the orthogonal planes. Part of the support assembly can be seen by the four dots above the carousel. The TLD and Au gold disks are difficult to see because they are small. There is a small rectangle below the bottom carousel disk. This is one set of TLDs (2 each) and an Au foil used to measure the dose. The Au foils and TLDs will be discussed later in this report.

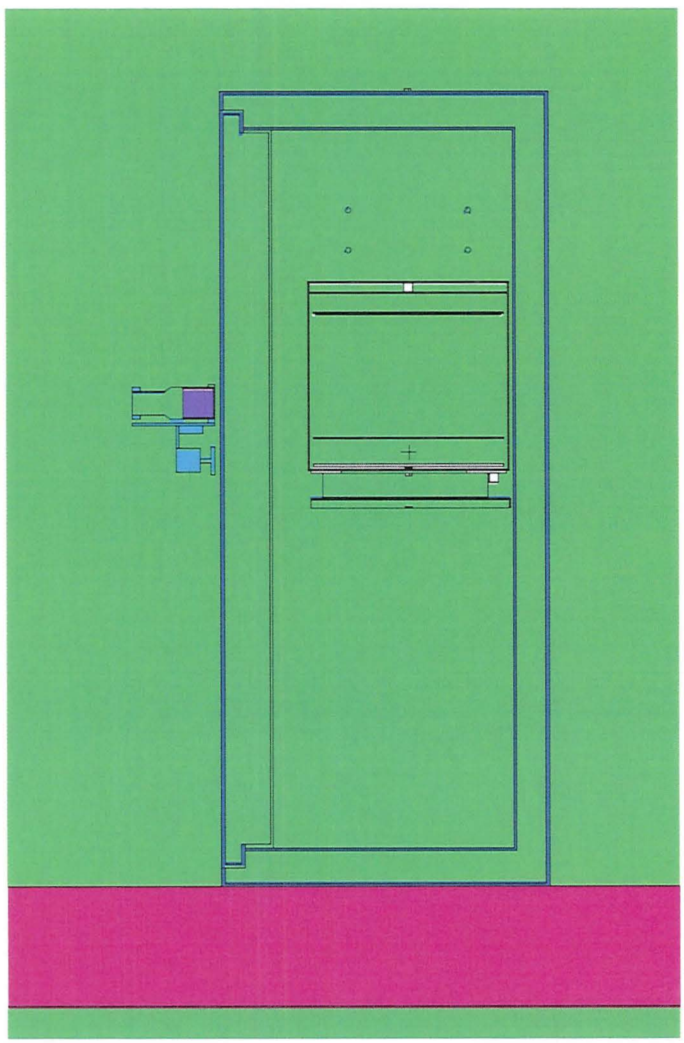

Figure 8: Detailed Model, Side View of the Carousel and Safe, X-Z

In Figure 9, one can see the arrangement of samples. Eight samples are in the carousel. One of the sample holders can be replaced with an ionization chamber probe. A small part of the NaI and BGO radiation detectors can be seen to the left.

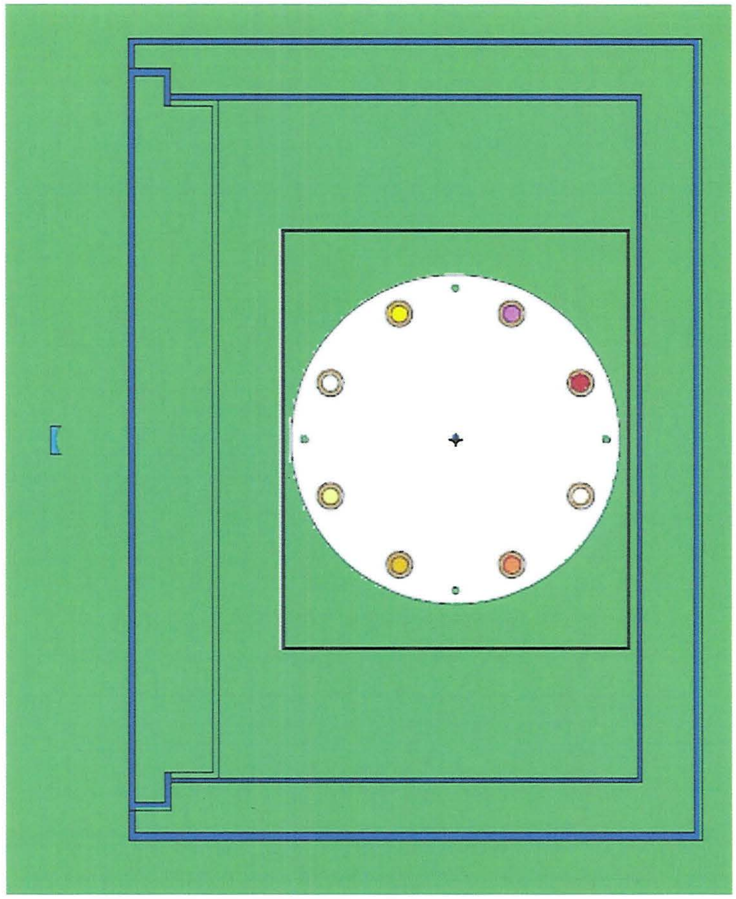

Figure 9: Detailed Model, Overhead View of the Carousel with the Samples

In Figures 10, 11 and 12, various planes are shown with the room, safe, and carousel. The plane views are all through the center of the samples.

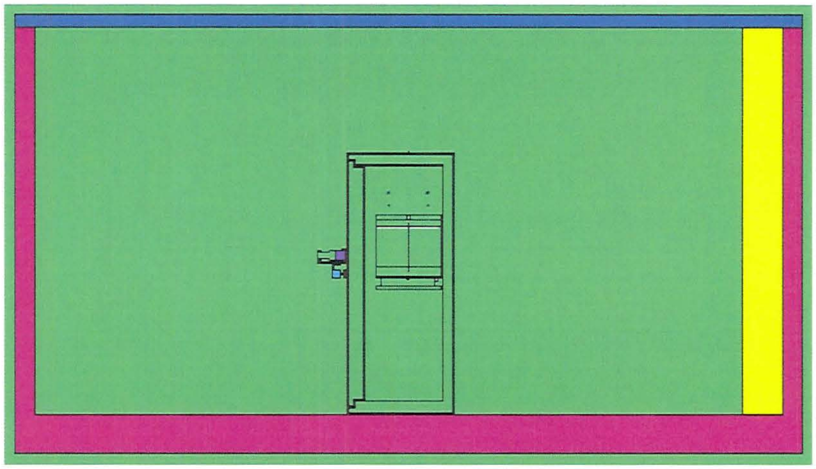

Figure 10: Detailed Model, Side View of the Room with the Carousel and Safe, X-Z

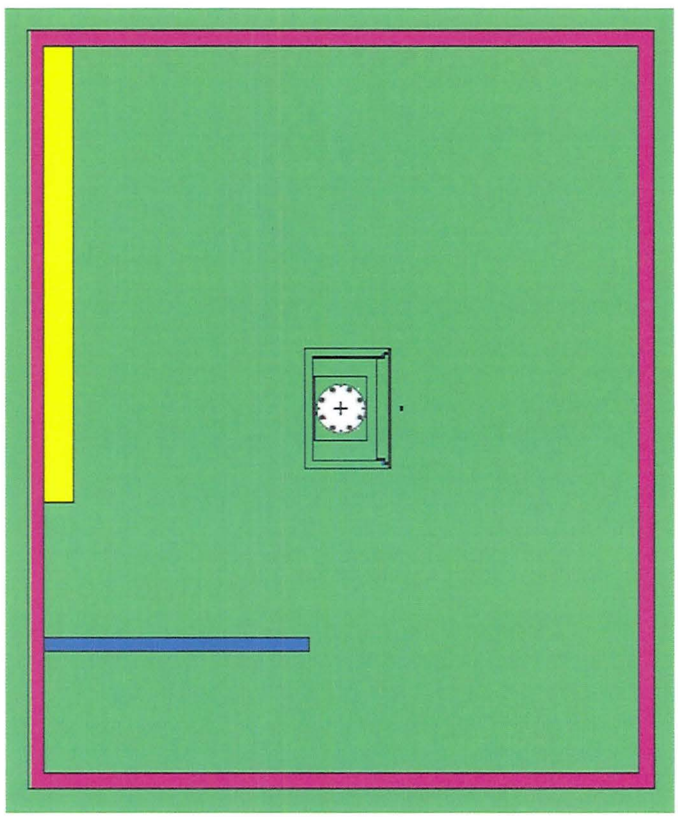

Figure 11: Detailed Model, Overhead View of the Carousel and Safe, X-Y

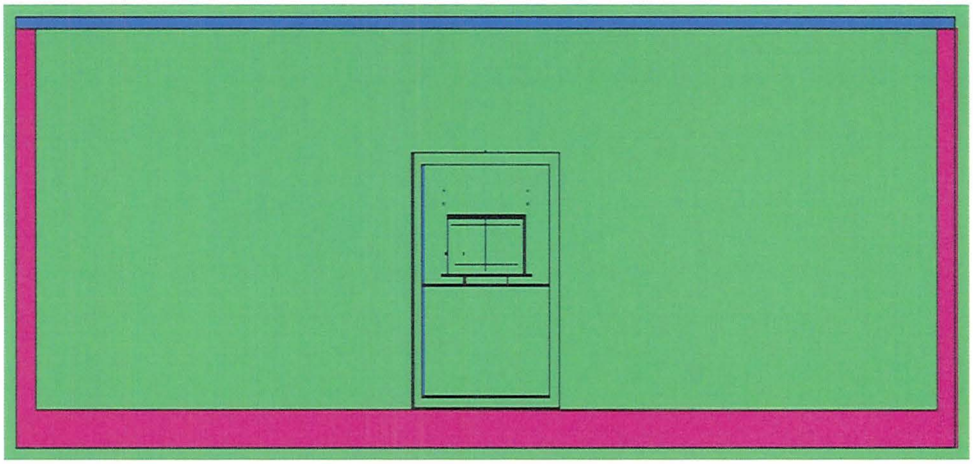

Figure 12: Detailed Model, Side View of the Room with the Carousel and Safe, X-Z

Source

^{137}Cs nominally gives $2.3x10^{-3}$ μCi/kg per hr per MBq (equates to 0.33 R/hr) at 1 meter. This empirical correlation is dependent on how the source is sealed and other factors, e.g. any γ attenuators. The decay scheme is shown in Figure 13. ^{137}Cs decays to ^{137}Ba 100% of the time via β^- with a 661.7 keV γ, which is why ^{137}Cs is useful as a radiation source. ^{137}Cs is a monoenergetic source and excellent for detector calibration. The daughter is ^{137}Ba, which decays via isomeric transition to stability.

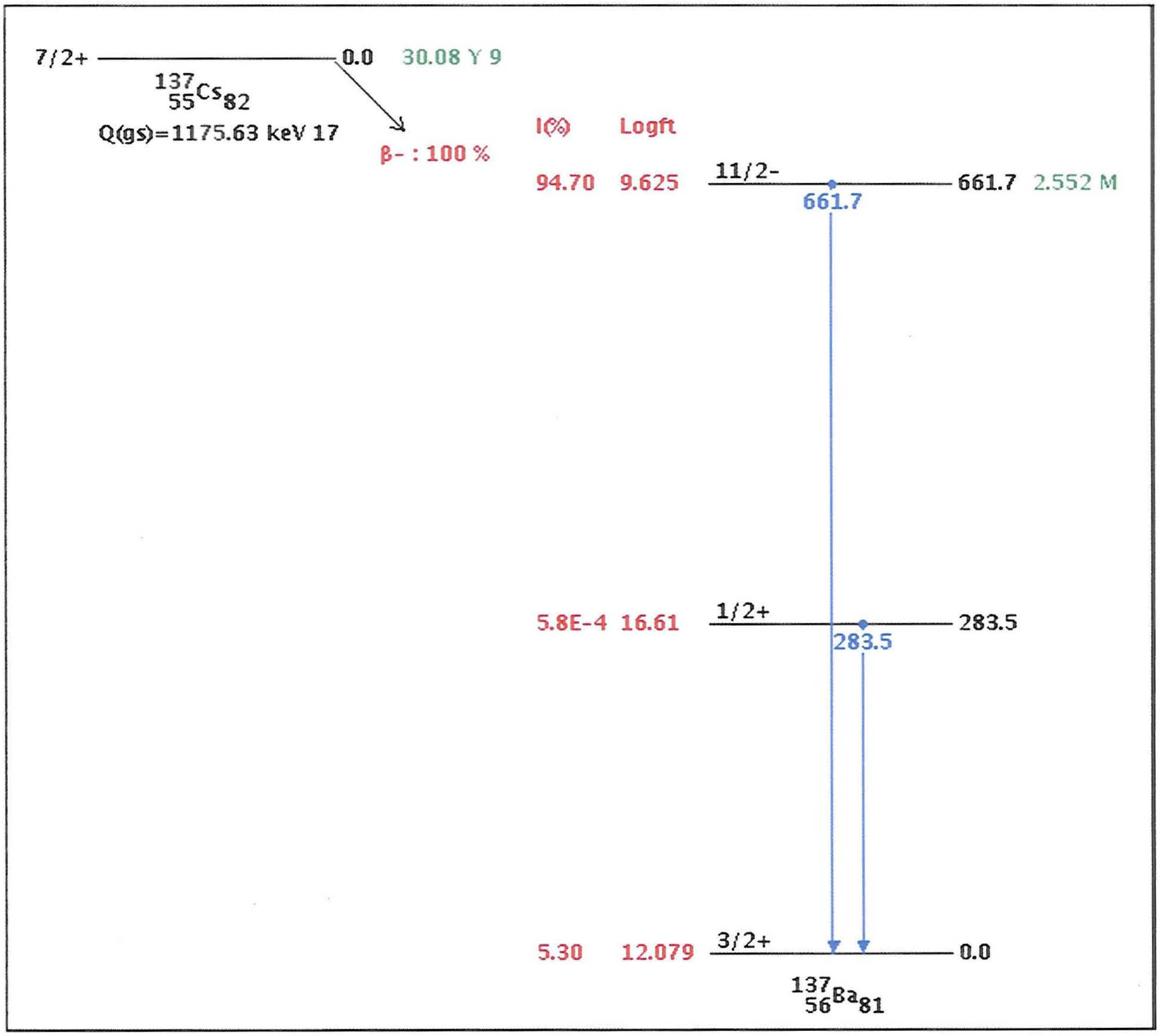

Figure 13: Decay Scheme of ^{137}Cs

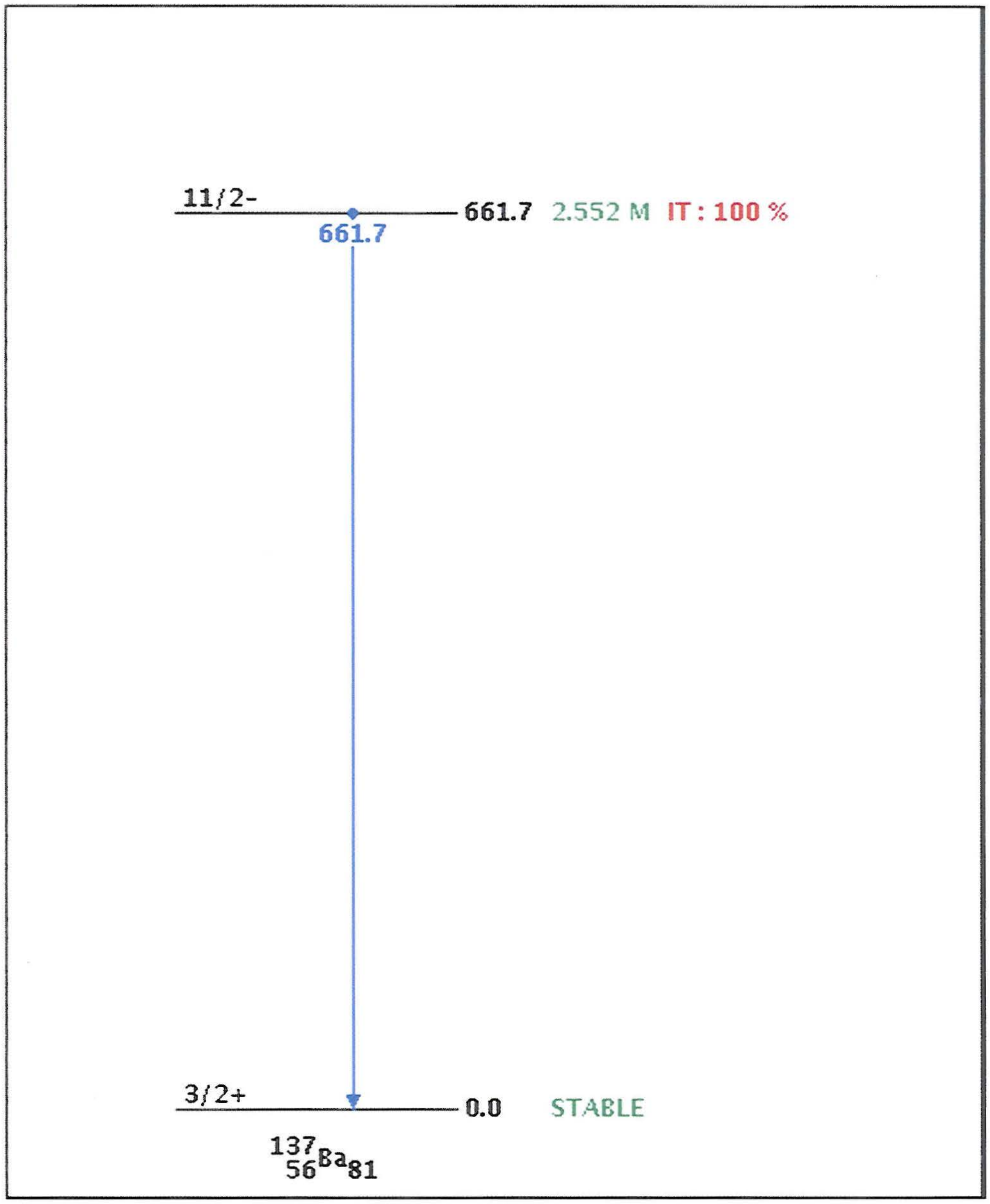

Figure 14: Decay Scheme for ^{137}Ba

Results

All of the results in this report were performed using the detailed model, with the exception of the results in Table 5, which show the difference between the simple and detailed models.

The “fmesh” tally for the samples in the X-Y plane is shown in Figure 15. The approximate radiation levels are shown on the drawing. The rad levels are plotted in a circular pattern. As a result of the different sample materials, the rad levels are not symmetric. It is symmetric within a fraction of an r/hr. The XY slice is through the center of the samples. Radiation levels will be much higher nearer the source. As given previously, ^{137}Cs gives about 0.33 R/hr per Ci at 1 meter, which equates to 2.18 r/hr@1 m. This is an empirical thumb-rule.

In Figures 16 and 17 side views are shown. The radiation levels are much higher in the side views. The side view cuts through the middle of the source. One should note that the 10 r/hr boundaries are approximately the same in all figures.

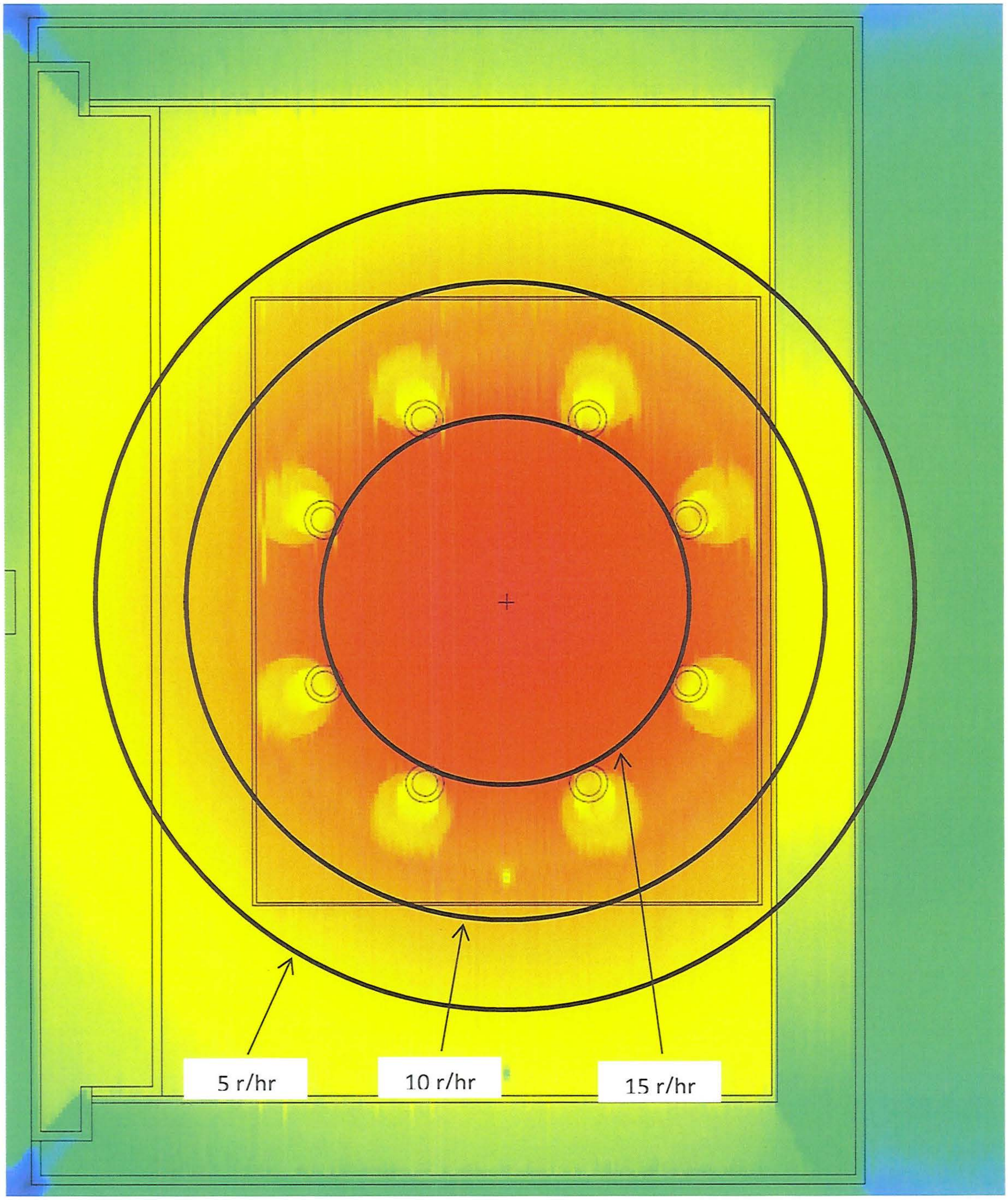

Figure 15: Radiation Field Overhead View of the Samples Including the Safe with the Door Closed (XY) View is Through the Center of the Samples

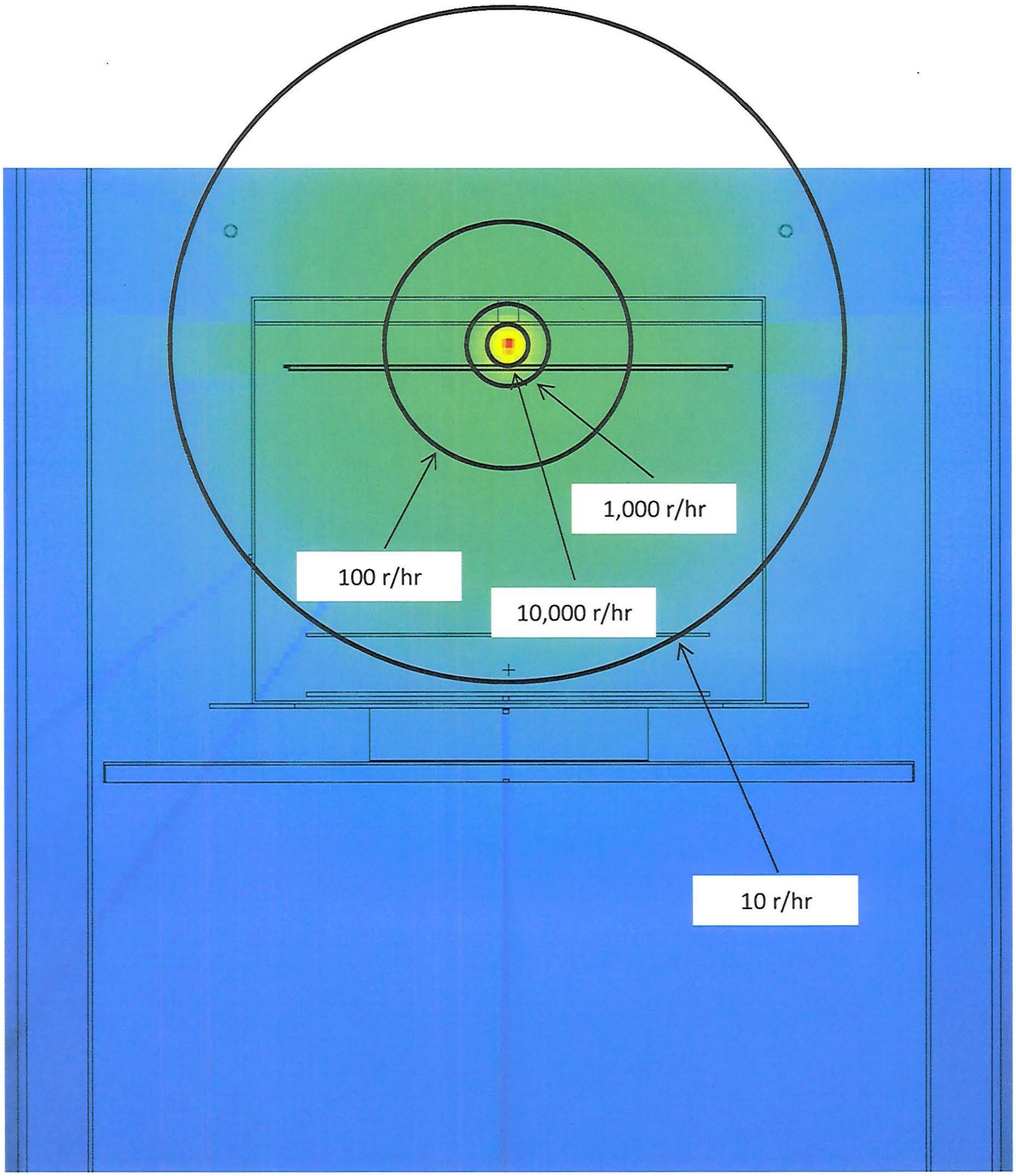

Figure 16: Radiation Field Side View of Including the Safe with the Door Closed (XZ)

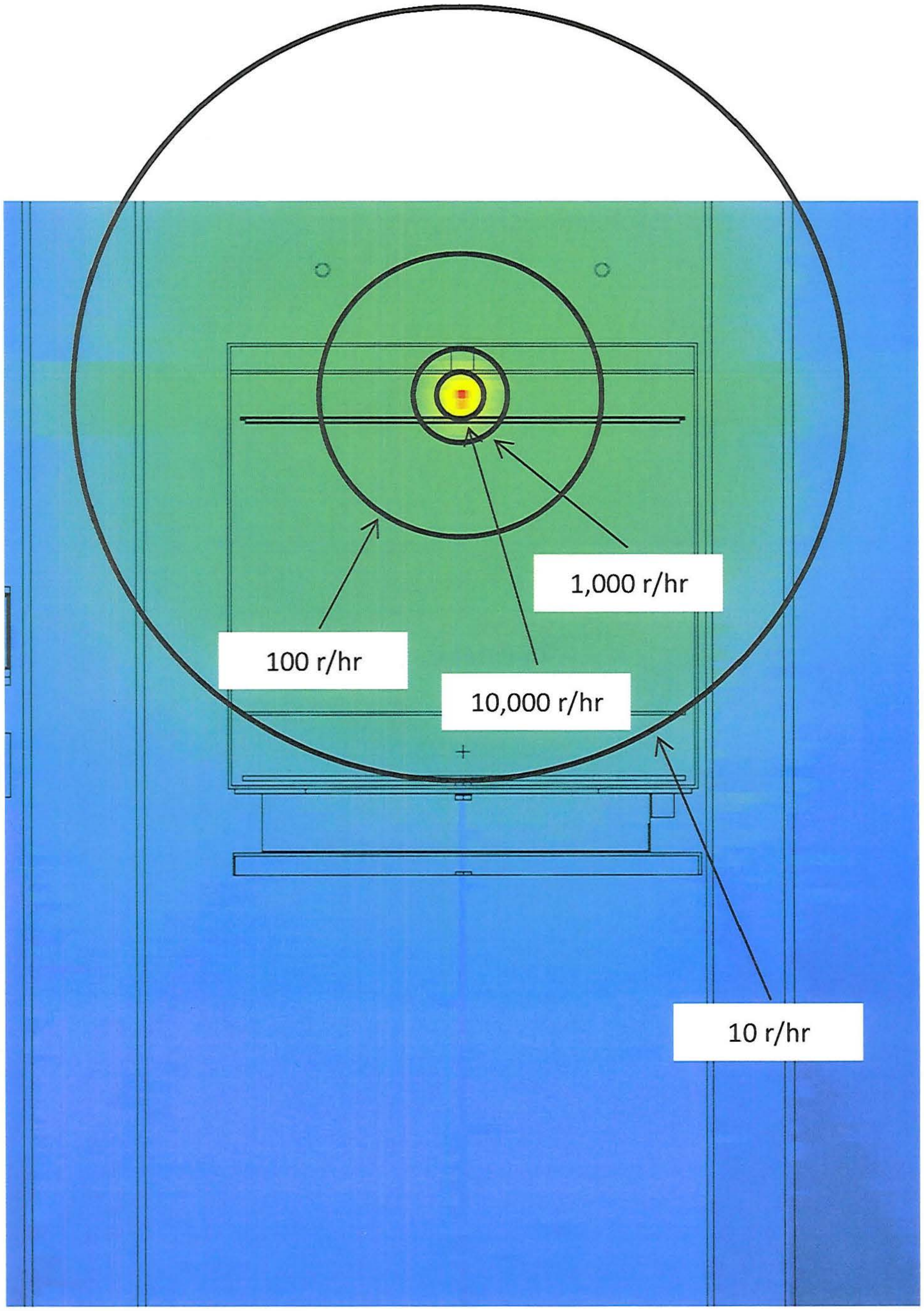

Figure 17: Radiation Field Side View of the Safe with the Door Closed (YZ)
Higher Levels than Figure 16 as a result of the Source Height
Figure 16 is about 30 cm Below the Source

The dose rate as a function of the radial distance from the source is shown in Figure 18. There is some attenuation from the sample can and the safe. These two features result in the non-r^2 behavior.

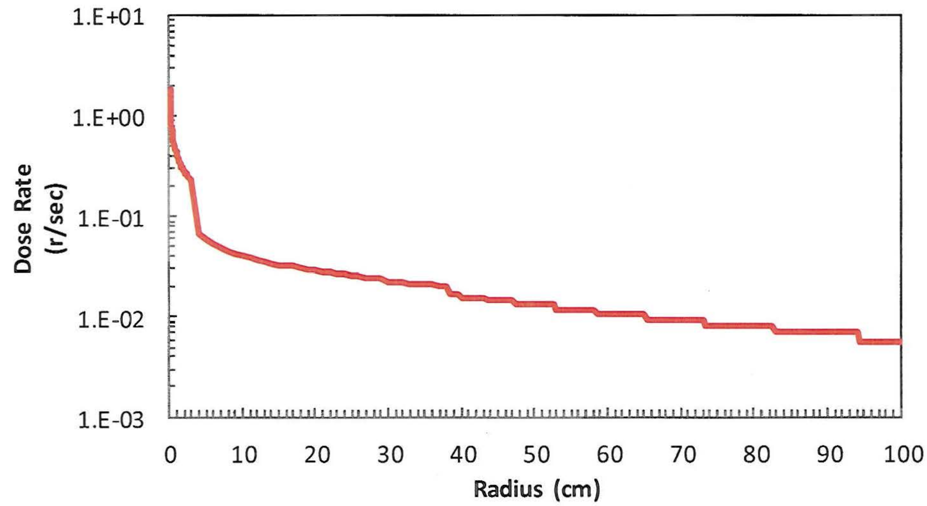

Figure 18: Calculated Dose Rate as a function of Distance into 4π

The concentration of elements in each of the eleven polymers is shown in Table 1. The nominal density of each polymer is given in Table 1. Polymers are typically large molecules. The composition is often given as an average from a smaller sampling of the larger molecule. The authors would like to give thanks to Gayle Kestel of W-11 who provided many of the polymer properties.

Table 1: Concentration of Elements and Isotopes for Polymers used in the Carousel

Element/Isotope	Wt Frac/ppm by mass	Density (g/cm^3)
	Polyurethane	
C	0.312	0.6557
O	0.154	
H	0.036	
N	0.499	
	Boron VCE	
C	0.149	1.6797
H	0.013	
N	0.015	
O	0.043	
^{10}B	0.699	
^{11}B	0.081	
	APO-BMI foam	
C	0.929	1.6795
H	0.017	
O	0.054	
Si	30 ppm	

P	50 ppm	
Na	60 ppm	
Silastic J		
C	0.264	1.1190
H	0.067	
N	0.005	
O	0.271	
Si	0.383	
Ti	0.010	
LK3626		
C	0.280	0.5426
H	0.065	
N	0.005	
O	0.305	
Si	0.344	
^{35}Cl	0.0000199	
^{112}Sn	0.001	
OXY 461		
C	0.296	1.0898
H	0.081	
N	28 ppm	
O	0.146	
Si	0.476	
^{35}Cl	190 ppm	
F	72 ppm	
S	251 ppm	
Br	72 ppm	
^{137}I	84 ppm	
Sylgard 184 (95% Sylgard 184 + 5% SiO_2)		
C	0.309	1.04
H	0.074	
O	0.239	
Si	0.378	
Sylgard 186 (66.4%) with Cabosil (33.6%)		
C	0.205	1.04
H	0.049	
O	0.338	
Si	0.408	
Cellular Silicon		
Si	1.000	2.33
Wilethane 44 adhesive		
H	0.041	1.43
C	0.544	
N	0.121	
O	0.294	

The calculated results are shown in Table 2. LK3626 results in the highest dose in one year. LK3626 has a high Z metal impurity, tin, which results in the higher dose. Since Tin is an impurity, the concentration will likely vary. If the concentration of Tin varies, the dose absorbed by LK3626 will also vary. A calculation was performed, which left Sn out. The dose is 2.3% lower. As a point of reference, the polyurethane foam is 3.07% lower than LK3626 with the Sn impurity. LK3626 without the impurities has a similar 1 yr dose as the other polymers. Polyurethane foam, OXY 461, Sylgard 186+Cabosil, and Sylgard 184 95/5 follow LK3626 in the absorbed dose. From an analyst's view of the model, the differences between these materials are likely within the standard deviation and the model uncertainty. In other words, these four materials may be statistically identical with respect to the dose absorbed.

Table 2: Detailed model Results for the Samples

Material	Mean	STD DEV (66%)	Dose Rate (rad/sec)	Dose (1 year)	1 Year STD Dev
lk3626	7.02E-22	0.0007	2.21E-02	6.98E+05	4.89E+02
VCE	7.00E-22	0.0007	2.21E-02	6.96E+05	4.87E+02
Polyurethane Foam	7.71E-22	0.0007	2.43E-02	7.67E+05	5.37E+02
Wilethane 44	7.35E-22	0.0007	2.32E-02	7.31E+05	5.12E+02
Oxy 461	7.81E-22	0.0007	2.46E-02	7.77E+05	5.44E+02
APO-BMI foam	6.93E-22	0.0007	2.19E-02	6.89E+05	4.82E+02
Cellular Si	7.02E-22	0.0007	2.21E-02	6.98E+05	4.88E+02
Sylgard 184 95/5	7.77E-22	0.0007	2.45E-02	7.73E+05	5.41E+02
Sylgard 186 + cabosil	7.67E-22	0.0015	2.42E-02	7.63E+05	1.14E+03
Silastic J	7.02E-22	0.0014	2.21E-02	6.98E+05	9.77E+02

* Separate calculation

The gold discs were used for dose measurements in the model given by SNL. A gold disk with two TLD packages is shown in Figure 19 and the results are shown in tables 3 and 4. The gold disk is a cylinder and is light green, lighter green than the surrounding air. Each gold disk is 0.5 cm thick and has a radius of 0.3175 cm. The TLDs are rectangular and are placed behind, in relation to the source, each Au disk. The white part of the TLD in Figure 19 is Aluminum Type H32. The TLD itself, magenta in Figure 19, is CaF_2:Mn (Mn doped). One could consider the combination of the three a dose measurement package.

Gold disks #1and #8 absorbed the least dose along with the TLDs (TLD1a, TLD1b, TLD8a, and TLD 8b) next to each disk. The two dose measurement packages are below the carousel and are the farthest from the source. The two dose measurement packages with the highest absorbed dose are #3 and #4, each is above the carousel, and, obviously, the closest to the source. As a point of reference, package #3 is 0.41 cm closer to the source. TLDs 6a and 6b have a higher dose than TLDs 3a and 3b while Au disc #6 has a lower dose than disk #3. Package 6 is closer to the source than package 3. Au disk #6 is adjacent to a structural steel bar that attenuates the γ dose absorbed by disk #6. TLDs 6a and 6b are a little more than ½ inch away from the structural steel and the dose is not attenuated as much as the disk.

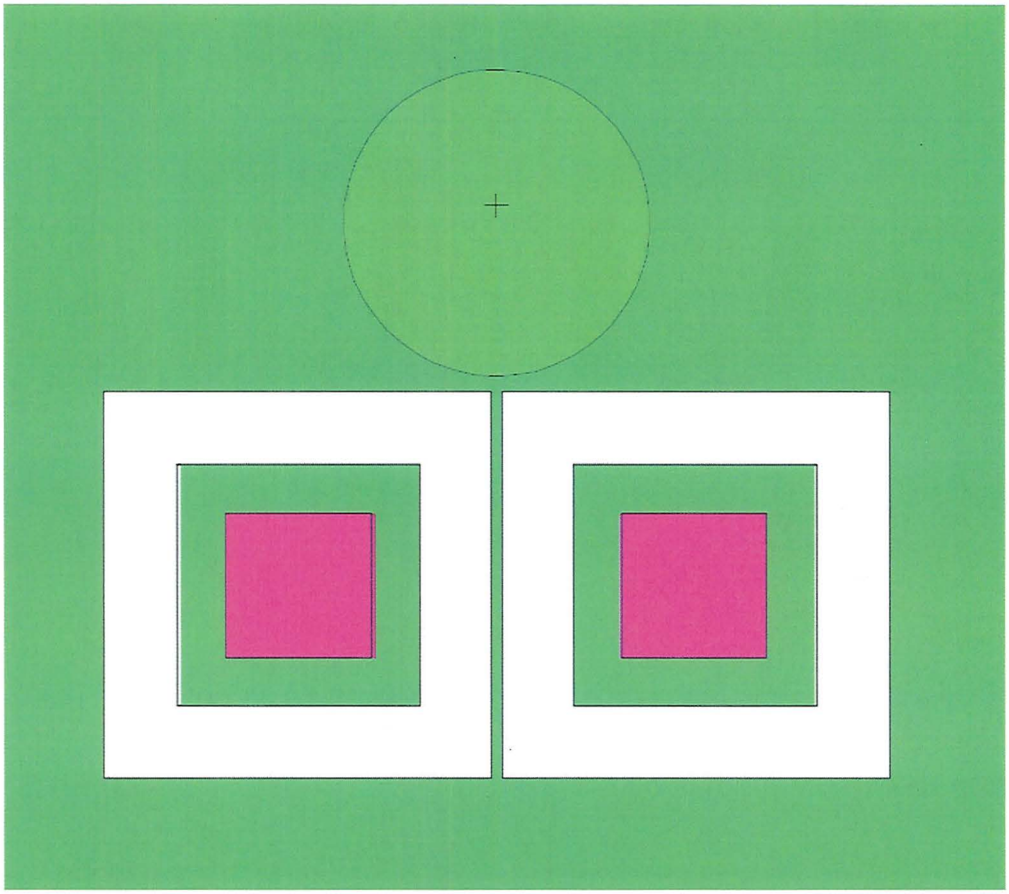

Figure 19: Schematic of Gold Disks and TLDs

Table 3: Detailed model Results for the Gold Disks

Tally	Disk	Mean	Std Dev (66%)	Dose Rate (rads/sec)	Dose (1 Yr)
316	Au Disk #1	6.62E-22	0.0060	2.09E-02	6.58E+05
326	Au Disk #2	2.17E-21	0.0034	6.85E-02	2.16E+06
336	Au Disk #3	3.66E-21	0.0026	1.15E-01	3.64E+06
346	Au Disk #4	2.36E-21	0.0032	7.43E-02	2.34E+06
356	Au Disk #5	1.19E-21	0.0045	3.76E-02	1.19E+06
366	Au Disk #6	2.98E-21	0.0028	9.40E-02	2.97E+06
376	Au Disk #7	2.98E-21	0.0028	9.40E-02	2.96E+06
386	Au Disk #8	6.02E-22	0.0065	1.90E-02	5.99E+05

Table 4: Detailed model Results for the TLDs

Tally	TLD	Mean	Std Dev (66%)	Dose Rate (rads/sec)	Dose (1 Yr)
406	TLD 1a	4.82E-22	0.0092	1.52E-02	4.79E+05
416	TLD 1b	4.84E-22	0.0091	1.53E-02	4.81E+05
426	TLD 2a	1.01E-21	0.0064	3.17E-02	1.00E+06
436	TLD 2b	1.00E-21	0.0065	3.16E-02	9.97E+05
446	TLD 3a	1.71E-21	0.0060	5.39E-02	1.70E+06
456	TLD 3b	1.71E-21	0.0060	5.40E-02	1.70E+06
466	TLD 4a	1.08E-21	0.0068	3.41E-02	1.08E+06
476	TLD 4b	1.08E-21	0.0068	3.39E-02	1.07E+06
486	TLD 5a	8.36E-22	0.0070	2.64E-02	8.32E+05
496	TLD 5b	8.38E-22	0.0070	2.64E-02	8.33E+05
506	TLD 6a	1.77E-21	0.0059	5.58E-02	1.76E+06
516	TLD 6b	1.83E-21	0.0058	5.76E-02	1.82E+06
526	TLD 7a	1.76E-21	0.0059	5.56E-02	1.75E+06
536	TLD 7b	1.79E-21	0.0058	5.66E-02	1.78E+06
546	TLD 8a	2.53E-22	0.0126	7.97E-03	2.51E+05
556	TLD 8b	2.53E-22	0.0126	7.97E-03	2.51E+05

The results of a comparison between the detailed and simple models is shown in Table 5. The models are described earlier in this report. The last column is the percent difference in the calculated results. The difference is less than one standard deviation. Statistically the results are the same. These results show that there is no difference between the simple and detailed models. Considering that the simple runs much faster and is much easier to understand and modify, the simple model is highly recommended.

Table 5: Comparison of Detailed Model vs Simple Model

	Detailed Model		Simple Model		
Material ↓	Mean	Std Dev	Mean	Std Dev	% Difference
LK3626	2.51E-02	0.0007	2.51E-02	0.0015	-0.0855
VCE	2.21E-02	0.0007	2.21E-02	0.0015	0.0071
Polyurethane Foam	2.43E-02	0.0007	2.44E-02	0.0015	-0.2022
Wilethane 44	2.30E-02	0.0007	2.30E-02	0.0015	-0.0590
OXY 461	2.44E-02	0.0007	2.44E-02	0.0015	-0.2003
API BMI Foam	2.17E-02	0.0007	2.17E-02	0.0015	0.1294
Sylgard 184 95/5	2.43E-02	0.0007	2.43E-02	0.0015	-0.1597
Sylgard 186+Cabosil	2.42E-02	0.0015	2.42E-02	0.0015	-0.1303
Silastic J	2.21E-02	0.0014	2.21E-02	0.0015	0.1426

Conclusion

All calculated results are satisfactory. The 66% confidence intervals for all results are less than 5%. The results are also consistent with the 137Cs thumb-rule, 2.18 r/hr @ 1 meter. Comparisons between the simple model and the detailed model show that there is no statistical difference between the two models for the sample results. It is recommended that for future calculations, one should use the simple model. The simple model runs faster, the results are easier to understand, and the model is easier to modify.

LK3626 received the largest dose, 791000±554 rads/yr. The lowest dose is 696000±487 rads/yr. The lowest calculated for Au disk #1 is 658000±3950 rads/yr and TLDs 1b 481000±4450 rads/yr. TLD 1a is statistically similar, 479000±4407 rads/yr. The Au disk with the highest absorbed dose is #3 at 3640000±9460 rads/yr. The TLD with the highest absorbed dose is 6a at 1820000±106 rads/yr. Au disk #6 is closer to the source, but was shielded by some structural steel.